The depth of the minimum between these two peaks was sensitive to the choice of background curve. Shown in the figure is the particular background curve which resulted in a zero minimum between these two maxima.

The interpretation here cannot be as simple as that suggested for selenium. The absorption corresponds to transitions from N_{IV-V} to $5d$. According to Callen,[5] the $5d$ band is made up of a broad band and a narrow band as before. However, the infrared absorption studies of Loferski,[7] interpreted in the light of Callen's work, indicate that the d perpendicular band begins less than 0.1 ev above the bottom of the d parallel band. Such a small separation would not have been resolved in the present study, so that the main absorption band between 39 ev and 46 ev is probably due to the combined effect of these two bands.

It is conceivable that exciton levels on impurity levels appear because the electron is leaving an ion behind with one extra positive charge. If this were the case, these levels would lie just below the conduction band and transitions into them might account for the small band on the low-energy side of the main band. This explanation is not entirely satisfactory because the impurity band proposed is wider than is customarily observed.[8] Also, the energy separation between the main band and the impurity band is large, in particular much larger than the 0.324 ev indicated by the data of Loferski as the separation between the valence and conduction bands. In addition, the width of the band is larger than 4.76 ev which is the work function of tellurium.[9]

[7] Joseph J. Loferski, Phys. Rev. 93, 707 (1954).

[8] E.g., L. G. Parratt and E. L. Jossem, Phys. Rev. 97, 916 (1955).
[9] Apker, Taft, and Dickey, Phys. Rev. 74, 1462 (1948).

Velocity Analysis of Thermionic Emission from Single-Crystal Tungsten

GEORGE F. SMITH
Electron Tube Laboratory, Hughes Research Laboratories, Culver City, California
(Received June 24, 1955)

Hutson has recently observed a non-Maxwellian distribution of thermionic emission from various crystallographic directions of a tungsten single crystal. It is suggested that the true distribution is Maxwellian, and that the observed distribution is due to an analyzer resolution of 0.24 volt. Factors which might affect resolution are discussed, and Hutson's numerical results are recalculated on the basis of this explanation.

HUTSON[1] has recently reported a careful experiment in which he observed a departure from Maxwell-Boltzmann distribution in the electron emission from single-crystal tungsten. This departure, a low-energy deficit, was the same in various crystallographic directions. As Hutson has pointed out, it is unlikely that the various crystal directions would be patchy in just such a way as to yield identical distributions. He also noted that the reflection coefficient which he uses to account for the distribution has, as yet, no satisfactory theoretical explanation.[2]

We suggest that some extraneous effect in the analyzer might affect analyzer resolution in such a way as to produce the observed distribution. Hutson's experimental points[3] for 2000°K are plotted in Fig. 1, along with a Maxwell-Boltzmann distribution modified by a 0.24-v rectangular resolution. It is seen that the match is very good. The 0.24-v figure was chosen to match the 2000°K data by interpolation from curves for resolutions of 0.2 v and 0.3 v. The same 0.24-v resolution figure was also applied to a Maxwell-Boltzmann distri-

bution for 1700°K. The match to Hutson's experimental points[4] for 1700°K was equally good.

Hutson calculates a tenfold better resolution, 0.024 v, from the dimensions of the analyzer and its operating potential. He states[1,5] that the same distribution was obtained when the resolution was electrically changed to 0.06 v by varying the magnetic field. He concludes that the instrumental resolution was adequate for the detail in the distribution. One might reason instead that the resolution was already limited at 0.24 v by some other factor and that it was not actually being changed by the variation in magnetic field. There is no obvious cause for a spurious loss in resolution. Interconnection of radial and axial energy components, caused by slight misalignment of the analyzer and accelerating diode appears to be ruled out by precision assembly.[1] Stray time-varying magnetic fields were too small to affect the resolution.[1] The presence of patch fields is perhaps the most plausible hypothesis. The configuration of the analyzer is given in reference 1, Fig. 1. A patch field at the central baffle slit would deflect electrons from their normal line focus. A simple order-of-magnitude calculation can be made if patch crystals in the tantalum

[1] A. R. Hutson, Phys. Rev. 98, 889 (1955).
[2] C. Herring and M. H. Nichols, Revs. Modern Phys. 21, 185 (1949), Sec. IV.4; D. W. Juenker *et al*, Phys. Rev. 90, 772 (1953); S. C. Miller, Jr., and R. H. Good, Jr., Phys. Rev. 92, 1367 (1953).
[3] From reference 1, Fig. 5.

[4] From reference 1, Fig. 11.
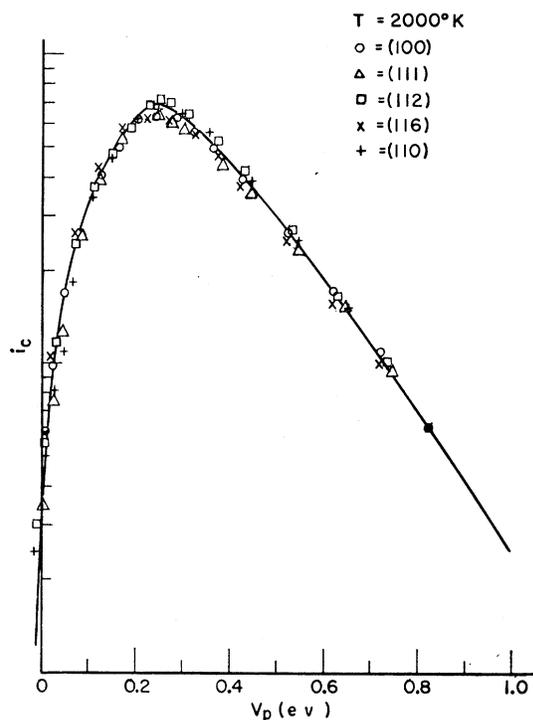[5] A. R. Hutson (private communication).

FIG. 1. Hutson's experimental points (reference 3) for 2000°K matched by a Maxwell-Boltzmann distribution modified by 0.24-v analyzer resolution.

baffle wall are comparable in linear dimension to the baffle slit width, 0.2 cm. The deflection at the exit slit would amount to

$$x = R(\Delta V)/2V_0, \qquad (1)$$

where R, the trajectory radius, is 3.175 cm; eV_0, the electron trajectory energy, is 3 ev; and ΔV is the patch work function difference. For clean tantalum, a reasonable value of ΔV is 0.5 v. This value gives a deflection ("effective" exit slit width) of 0.26 cm, as compared with actual slit width of 0.026 cm. Since resolution is proportional to exit slit width, 0.26 cm corresponds to 0.24 v resolution. To determine whether Eq. (1) is applicable, Hutson[5] has opened the analyzer tube to measure the crystal grain size at the baffle slit. A photograph of the etched tantalum surface shows grains of a few times 10^{-3} cm in linear size, nearly a hundred times smaller than the slit width. Thus it is unlikely that baffle slit patchiness alone could produce the deflection required to give a resolution of 0.24 v. There is still the possibility that patch effects were enhanced by the presence of contaminants on the tantalum walls. Although great care was taken in the evacuation schedule,[1] it is extremely difficult to thoroughly out-gas large pieces of tantalum. The presence of at least a detectable degree of contamination is indicated by one observed change[1] of analyzer work function due to bombardment heating of the anode. Martin[6] and others have noted that adsorption of contaminants is, in general, extremely

---

[6] S. T. Martin, Phys. Rev. 56, 947 (1939).

TABLE I. Revised summary of single-crystal emission constants. Hutson's values have been altered as required if the distribution shape is due to analyzer resolution.

Direction	$d\phi/dT$ (v/deg)	$A\alpha$ (amp/cm² deg²)
(111)	$+4.9 \times 10^{-5}$	92
(112)	-6.7×10^{-5}	55
(116)	$+4.9 \times 10^{-5}$	94
(100)	-0.1×10^{-5}	104

sensitive to surface orientation, and that patch contact potentials and hence patch fields are often greatly enhanced by the presence of even small amounts of contaminant.

If the shape of the experimental energy distribution curves is attributed to analyzer resolution, Hutson's numerical results are affected as follows: (1) The true work function differences among the various crystal faces[7] are unchanged. (2) The temperature derivatives of the work function[8] are increased by 1.6×10^{-5} v/deg.[9] This is a very small change, being just equal to the stated uncertainty of the measurement. The adjusted temperature derivatives are given in Table I. (3) Hutson's values[10] of $A\alpha$ (A is the emission constant, 120 amp/cm² deg²; α is the energy-independent part of the transmission coefficient) must be recalculated using the new temperature derivatives and assuming no energy-dependent reflection. The new values are given in Table I. (4) The best estimates of true work function[11] for the (111), (112), (116), and (100) directions are increased by 0.08 v, restoring the constant parts to their respective Richardson ϕ^* values. The temperature coefficients must also be replaced by the new values from Table I.

The new values of $A\alpha$ from Table I seem to indicate a value of about 0.8 for α [using the (111), (116), and (001) directions]. This corresponds to an exclusively energy-independent reflection coefficient of 0.2. On the other hand, Nottingham's reflection coefficient, as used by Hutson, gives $\bar{R} = 0.52$ at 2000°K. When this is combined with his value of $\alpha = 0.9$, a total integrated reflection coefficient of about 0.6 is obtained.[12] It is believed that the new interpretation is in better agreement with theory.[2]

We are indebted to Dr. Hutson for a prepublication copy of his manuscript.

---

[7] Reference 1, Table I.
[8] Reference 1, Table II.
[9] A. R. Hutson, in private communication, has carried through an accurate general comparison of the two methods of matching curves to obtain values of $d\phi/dT$. He does not refer to the experimental curves except to note that the match of Fig. 1 is satisfactory. We have directly checked the experimental curves of reference 1 with less precision, to show that the two methods give only slightly different results.
[10] Reference 1, Table V.
[11] Reference 1, Table VI.
[12] It is apparently inconsistent that the new method can give a much smaller integrated reflection coefficient from the same values of A^* and only slightly different values of $d\phi/dT$. This is due to a considerable contribution from $d\bar{R}/dT$ in Eq. (6) of reference 1 when Nottingham's reflection coefficient is used.